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IMPROVED COORDINATES OF FEATURES IN THE VICINITY OF THE VIKING 1 LANDER SITE ON MARS

PREPARED FOR THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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PREFACE

This report is based on computations of the control net of Mars which were initiated early in 1972 shortly after the Mariner 9 spacecraft went into orbit around that planet. Subsequently, control net updates of August 1972, April 1973, and June 1973 have been published under the sponsorship of the Mariner 9 project of the Jet Propulsion Laboratory; and updates of May 1974, May 1977, and February 1978 have been published under the sponsorship of the Planetary Geology Office, Planetary Division, National Aeronautics and Space Administration.

The present work establishes a continuous photogrammetric corridor between Airy-0 (on the prime meridian of Mars) and the Viking 1 lander site (about 48° to the west) to improve the measurement of the longitude of the Viking 1 lander site and the accuracy of the coordinates of features in its vicinity.

SUMMARY

Data from a strip of 117 frames (principally Viking Orbiter photographs) joining the areas around Airy-0 and the Viking 1 lander site were used in the GIANT computer program to improve the areographic coordinates of Mars surface features in this region. Because Airy-0 defines the prime meridian on Mars, this photogrammetric tie-line permitted an independent determination of the longitude of the Viking 1 lander site as $47\overset{\circ}{.}968 \pm 0\overset{\circ}{.}05$. The longitude did not change from prior measurements (Davies et al., 1978); however, the error dropped from about $0\overset{\circ}{.}1$ to $0\overset{\circ}{.}05$.

Longitudes of a number of features in the vicinity of Airy-0 were determined with a standard error of about 40 m ($0\overset{\circ}{.}001$). Similarly the latitudes of features near the lander site were determined to the following standard errors: 31 points to $\pm 0\overset{\circ}{.}003$; 40 points to $\pm 0\overset{\circ}{.}004$; and 11 points to $\pm 0\overset{\circ}{.}005$.

ACKNOWLEDGMENTS

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CONTENTS

I. INTRODUCTION

The computation of planimetric coordinates of topographic features on Mars began with the Mariner 6 and 7 missions (Davies, 1972) and was extended to all regions of the planet with the Mariner 9 pictures (Davies and Arthur, 1973). The accuracy of these coordinates was estimated to range from 10 km to 22 km. Over the years, many additional points and Mariner 9 pictures were added to the computations to improve this accuracy and to strengthen the control net of Mars. The Viking pictures were introduced into the control net computations as they became available, beginning in 1976, and the planetwide net now consists of a mixture of pictures from both missions. The most recent publication (Davies et al., 1978) contains horizontal coordinates of 4138 control points computed from 27,582 measurements on 1009 Mariner 9 and 204 Viking orbiter pictures. The accuracy of these coordinates has greatly improved and is estimated to range from 5 km to 12 km.

Initially, the planetary radii at the control points were derived directly from the Mariner 9 radio occultation measurements (Davies and Arthur, 1973). A few photogrammetric studies led to some local radii measurements and these were incorporated into the control net; however, most of the radii have been taken from the elevations on the U.S. Geological Survey topographic series of maps. The elevations for these maps were derived by Wu (1975, 1978).

Radio tracking data from both Viking landers have been used to obtain very accurate values for the direction of Mars' spin axis and its rotation rate (Mayo et al., 1977; Michael, 1979). The precision of the measurements should improve with more extended tracking data (Reasenberg and King, 1979). Included in the solution for the rotation rate and direction of the spin axis of Mars are the latitude, right ascension at a particular epoch, and planetary radii at the lander sites. The results for the Viking 1 lander site are:

Areographic Latitude (ϕ')	Aerocentric Right Ascension @ JD2443144.5 = Jan 1.0, 1977 E.T. (α_o)	Radius (km)	Source
22°482 ± 0°002	277°314 ± 0°002	3389.38 ± 0.06	Mayo et al., 1977
22°480 ± 0°003	277°312 ± 0°002	3389.32 ± 0.06	Michael, 1979

A study was made by Morris, Jones, and Berger (1978) to locate the Viking 1 lander on orbiter pictures. The resolution in the orbiter pictures is much too low to see the lander, but the authors were able to identify common features in orbiter and lander pictures. By this technique the location of the lander was estimated to be at line 742, sample 430, on orbiter picture 27A63. The identification was thought to be accurate to 200 m; the (two-pixel) resolution of this frame is 80 m.

Subsequent to the completion of the Morris, Jones, and Berger study, a new high-resolution (16 m, two-pixel) picture, 452B11, was taken of the lander area. Morris and Jones (1980) conducted a new study and, with increased confidence, placed the Viking 1 lander at line 293, sample 1099, on that frame. They estimate the standard error in identifying the lander location to be about 40 m in longitude and 30 m in latitude.

The present study was designed to improve the measurement of longitude of the Viking 1 landing site and the accuracy of the coordinates of features in the area around the landing site. The longitude must be measured photogrammetrically from the small crater, Airy-0, which defines the 0° meridian on Mars. This report will (1) discuss the computer program, GIANT, which was used to perform the analytical triangulations; (2) describe the photogrammetric computation of the longitude of the Viking 1 lander site; and (3) present improved coordinates of features in the vicinity of the Viking 1 lander site.

II. THE GIANT COMPUTER PROGRAM

All the analytical triangulation computations in this study were made using the General Integrated Analytical Triangulation (GIANT) computer program (Version III, 1976). This program, written by Atef A. Elassal of the U.S. Geological Survey, Topographic Division, Reston, Virginia, is an extension and modification of the earlier Multiple Station Analytical Triangulation (MUSAT) program. The original MUSAT program was developed for the U.S. Army Engineer Geodesy, Intelligence, Mapping Research and Development Agency, now the U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia. The objective of GIANT and its predecessors is to employ data from high-altitude photographs (image measurements, camera position, and orientation parameters) to generate high precision geographic coordinates of points on the surface of the earth for use in the making of maps. It is applicable, with appropriate modifications, to planets other than Earth.

GIANT is capable of handling, in a single run, a block of up to 460 photographs containing as many as 450 different ground control points. The program, for frame photography, is very general and uses an efficient partitioning algorithm for inverting the coefficient matrix of the normal equations. Input data can be constrained by weights, and standard errors of all output parameters are computed. Frederick J. Doyle, Atef A. Elassal, Morris L. McKenzie, and Sherman S. C. Wu of the U.S. Geological Survey provided us with a program source card deck, sample data card deck, sample computer runs, and some documentation.

III. THE LONGITUDE OF THE VIKING 1 LANDER

The 0° longitude on Mars is defined as that meridian passing through the center of the small crater, Airy-0 (de Vaucouleurs et al., 1973); the longitudes of all other points on Mars are measured relative to this origin. Airy-0 was defined on the Mariner 9 narrow-angle frame 533-03 (Davies and Arthur, 1973) and was seen again on the high-resolution Viking picture 746A46 (see Fig. 1).

The longitude of the Viking 1 lander in the planetwide control net computation (Davies et al., 1978) was determined primarily from Mariner 9 pictures in the area between Airy-0 and the Viking 1 landing site. The (2-pixel) resolution of these pictures was between 1 km and 2 km. To improve this measurement, a strip of 117 Mariner 9 and Viking pictures was selected to tie these two areas together. The (2-pixel) resolution of the Viking mapping frames was about 0.5 km. High-resolution pictures were then used at each end to tie the strip to the crater Airy-0 and the precise landing site (Morris and Jones, 1980). Figure 2 shows the path of the strip; 2564 measurements of 450 points were used in the computation. This curved path, rather than a more direct route, was selected to pass over Viking radio occultation points (Lindal et al., 1979) where the planetary radii have been very accurately measured. The strip passes over nine occultation points. A strip farther north is certainly desirable and is planned for the future. Perhaps planetary radii along the northern strip will be determined from Earth-based radar data. The frames used in the photogrammetric strip were:

Mariner 9	*Viking*				
137-31	20A46	20A88	488A16	615A56	746A46-47
139-15	20A48	20A90	615A24-36	651A35	825A41
139-18	20A50	27A28	615A42	651A51-54	825A43
166-30	20A52	27A30	615A44	651A56-66	825A45
168-30	20A54	27A32-36	615A46	651A76	827A01-09
533-01	20A62	27A58	615A48	651A78	827A11
533-03	20A64	27A60	615A50	651A80	827A21-31
	20A66-75	27A62-66	615A52	651A82-86	
	20A86	452B10-12	615A54	651A88	

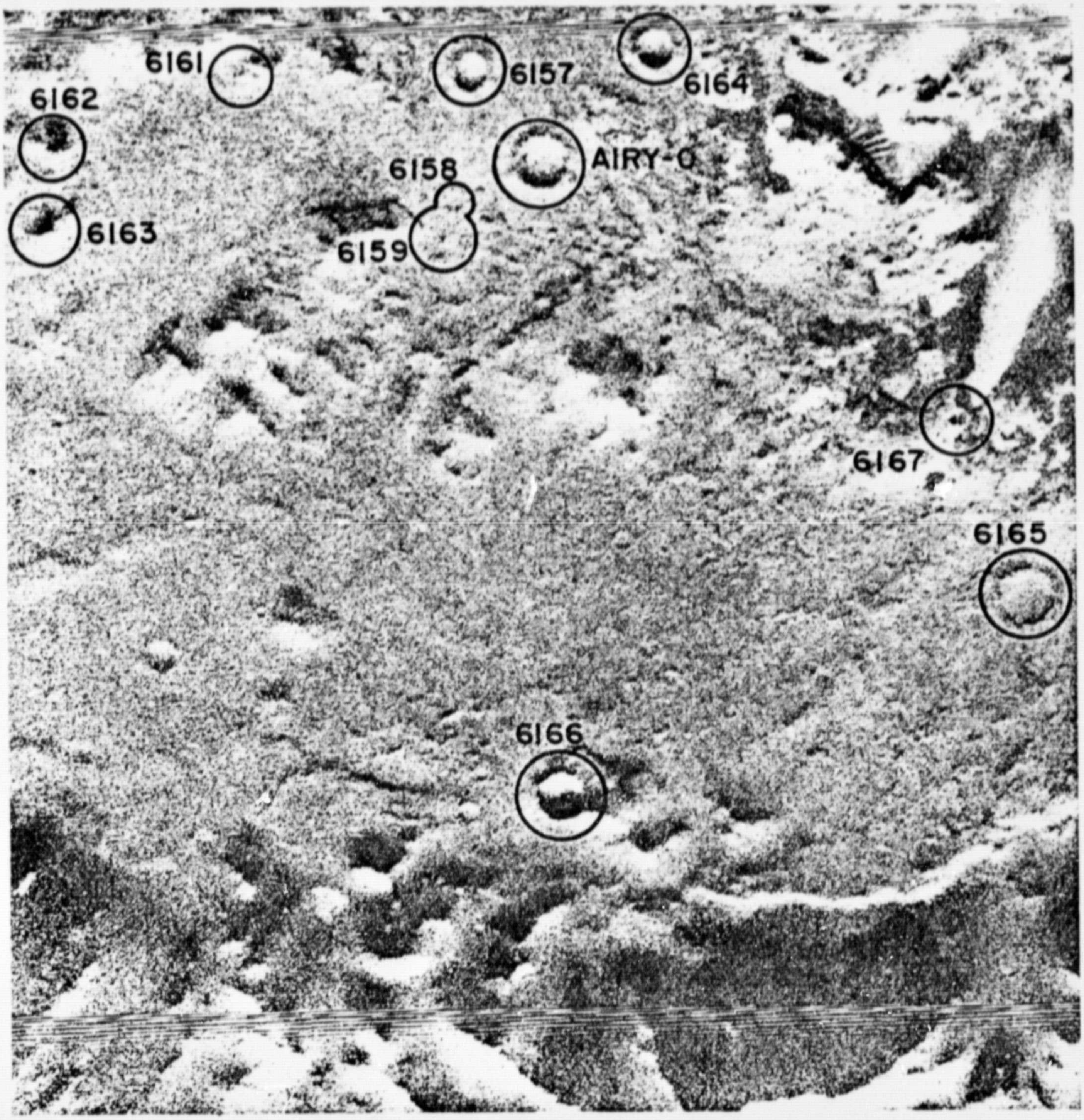

Fig. 1 — Viking picture 746A46, with (2-pixel) resolution of 30m, showing Airy-0 and nearby points

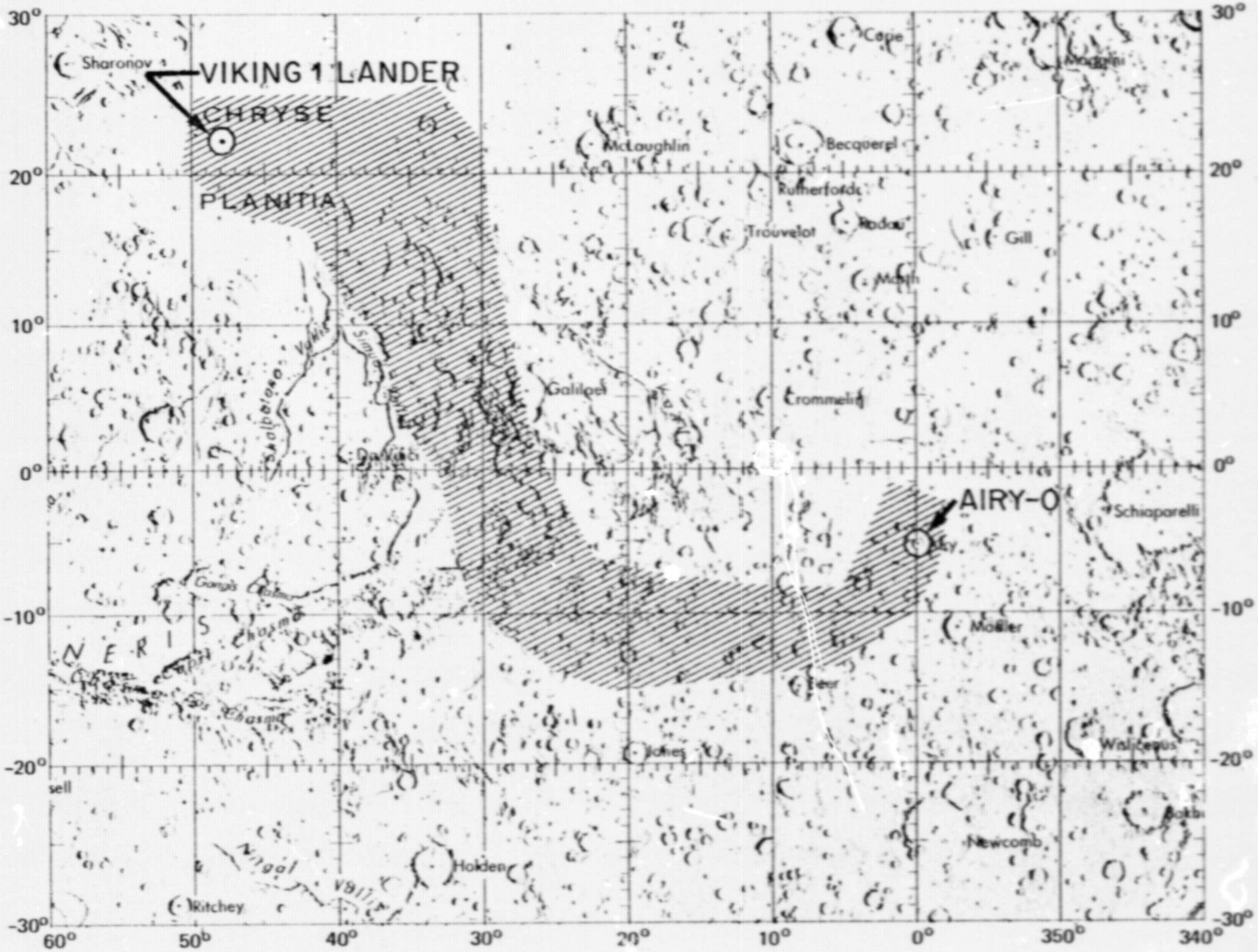

Fig. 2 — Cross-hatching shows the path of the photogrammetric strip connecting Airy-0 with the Viking 1 lander site

In the analytical triangulation, the camera station positions were not allowed to vary--they were derived from the *Supplementary Experimenter Data Record (SEDR)* published by JPL. Also, there was no solution for the planetary radii at the control points; this was a purely planimetric adjustment. As would be expected, the standard errors in longitude of the control points were small, about 40 m (0°001), in the region of Airy-0 (Fig. 1) and increased continuously until they became about 3 km in the vicinity of the Viking lander. Table 1 gives the coordinates of points identified on Fig. 1. The longitude of the lander site is 47°968 ± 0°05. The measurement did not change from Davies et al. (1978); however, the error dropped from 6 km (0°1) to 3 km (0°05). Airy-0 is point 0000; the Viking lander is point 4700.

To test the sensitivity of the longitude measurement of the lander site, a second analytical triangulation was made with the latitude of Airy-0 shifted toward the equator by 0°2 (about 12 km). This led to a westward shift of 0°017, or 1 km, in the longitude of the lander. Thus the longitude measurement is relatively insensitive to any small change in the latitude of Airy-0. The error in the latitude of Airy-0 is thought to be less than 0°1 (about 6 km).

Table 1

COORDINATES OF POINTS
IDENTIFIED ON FIG. 1

Point	Latitude, $\phi'°$	Longitude, $\lambda°$
Airy-0	-5.142	0
6157	-5.137	359.973
6158	-5.119	359.997
6159	-5.111	0.006
6160	-5.125	359.960
6162	-5.040	359.938
6163	-5.026	359.956
6164	-5.180	359.990
6165	-5.194	0.151
6166	-5.070	0.137
6167	-5.200	0.106

Table 2 shows the new coordinates for those control points that were listed in Davies et al. (1978) and used in this adjustment. Some 286 additional points were also used in the adjustment but are not listed here.

Table 2

AREOGRAPHIC COORDINATES OF THE CONTROL POINTS

Point	Latitude, $\phi'°$	Longitude, $\lambda°$	Point	Latitude, $\phi'°$	Longitude, $\lambda°$
0000	-5.142	0.000	3180	-13.045	21.157
0031	-5.912	359.041	3186	-12.428	26.447
0035	-4.747	2.613	3189	-10.150	17.102
0480	24.867	47.076	3196	-11.514	19.970
0488	10.871	34.817	3197	-11.492	21.370
0527	4.966	38.816	3200	-7.739	22.193
0528	4.114	33.565	3201	-7.986	21.724
0529	6.178	34.912	3209	-8.197	24.216
0530	9.069	37.194	3210	-9.100	23.561
0532	15.470	34.660	3211	-9.448	24.687
0534	12.655	30.892	3212	-10.340	26.207
0823	-7.646	358.454	3222	-14.691	24.291
0825	-4.645	0.492	3223	-15.199	21.412
0827	-5.382	358.687	3225	-15.682	24.365
0828	-3.770	358.434	3226	-16.705	23.414
0829	-8.597	5.146	3229	-10.942	16.809
1255	26.015	37.686	3230	-13.182	17.532
3001	7.586	39.573	3236	-17.145	45.538
3002	4.172	35.942	3238	11.460	38.230
3003	6.744	39.460	3239	10.560	38.740
3004	6.293	33.135	3245	-2.023	31.243
3011	14.333	31.179	3321	27.316	41.559
3012	13.780	33.048	3327	22.687	31.439
3030	26.432	46.244	3332	17.567	30.212
3031	25.520	44.179	3333	17.963	32.295
3032	22.046	48.564	3334	17.276	34.236
3033	18.111	32.740	3342	11.184	42.212
3034	18.724	36.486	4376	20.434	49.434
3035	18.913	32.168	4377	20.269	49.325
3043	-4.281	11.116	4379	20.231	49.121
3054	-0.756	4.542	4380	20.775	48.978
3055	-1.475	359.032	4381	20.686	48.822
3141	-3.814	30.551	4382	20.560	48.666
3146	6.352	29.016	4383	21.203	48.524
3163	-17.644	26.936	4384	20.839	48.305
3164	-18.291	22.923	4391	22.130	47.014
3166	-19.040	24.241	4392	21.920	46.832
3167	-20.092	24.236	4394	22.422	46.830
3168	-19.976	23.175	4395	22.342	46.968
3177	-13.345	23.389	4396	22.814	48.404
3179	-12.105	25.353	4397	22.598	48.262

Table 2 (continued)

Point	Latitude, ϕ'°	Longitude, λ°	Point	Latitude, ϕ'°	Longitude, λ°
4398	22.316	48.234	4582	22.458	48.109
4399	22.359	48.050	4583	22.646	48.003
4401	23.119	47.975	4584	22.533	48.071
4402	22.873	47.730	4585	22.489	47.923
4403	22.583	47.778	4586	22.503	47.932
4406	23.000	47.256	4588	22.484	47.980
4407	23.067	47.117	4589	22.459	47.983
4408	23.248	46.938	4599	22.291	48.102
4410	22.905	47.154	4600	22.074	48.100
4416	22.527	46.975	4606	22.437	47.984
4417	22.177	47.187	4607	22.420	48.006
4418	22.096	47.339	4608	22.413	47.978
4419	22.736	47.632	4609	22.393	47.989
4420	22.655	47.760	4610	22.385	48.010
4421	22.425	48.205	4611	22.379	47.982
4422	21.891	47.582	4612	22.512	47.955
4423	21.761	47.487	4613	22.485	47.964
4424	21.633	47.280	4614	22.473	47.961
4425	21.471	47.202	4615	22.466	47.960
4426	21.755	47.891	4616	22.443	47.967
4427	21.627	47.954	4617	22.467	47.999
4428	21.408	47.951	4618	22.510	48.006
4430	20.999	48.233	4619	22.444	48.037
4461	20.785	46.850	4620	22.431	48.089
4462	20.386	46.563	4621	22.388	48.062
4476	21.683	47.133	4622	22.420	48.038
4480	20.544	47.526	4623	22.392	47.882
4510	6.160	41.474	4624	22.307	47.960
4511	7.404	42.496	4625	22.314	47.891
4515	22.280	47.456	4626	22.346	47.928
4519	22.260	47.717	4627	22.345	47.994
4520	21.994	47.921	4628	22.382	47.860
4521	21.625	48.446	4629	22.406	47.848
4525	21.280	48.958	4630	22.541	47.815
4527	21.835	47.410	4631	22.494	47.828
4528	21.281	47.135	4632	22.445	47.853
4529	21.464	48.196	4643	21.701	50.336
4537	22.707	47.903	4669	20.550	49.231
4549	22.330	46.862	4671	21.381	49.921
4579	22.638	47.524	4679	20.576	50.613
4580	22.563	47.529	4700	22.480	47.968

IV. COORDINATES OF POINTS IN THE VICINITY OF THE VIKING 1 LANDER

The coordinates of the Viking 1 lander used in this study are those given by Michael (1979) and were selected because these values were derived from a larger data set received over a longer time base than those given by Mayo et al. (1977). The standard error of the latitude measurement is given as 0°003 (180 m). The standard error of the identification of the Viking 1 lander site on frame 452B11 was estimated to be about 30 m. These sources of error must be combined with the photogrammetric error to arrive at the overall accuracy of the latitude coordinates of the control points. With regard to longitude, the 40 m standard error of identification of the Viking 1 lander site is negligible compared to the 3 km photogrammetric standard error associated with points in that region. Points near the Viking 1 lander site are shown in Fig. 3.

Those points with a photogrammetric standard error of latitude less than 32 m and an overall standard error of latitude of 0°003 are:

4582	4609	4617	4626
4585	4610	4618	4627
4586	4611	4619	4628
4588	4612	4620	4629
4589	4613	4621	4630
4606	4614	4623	4631
4607	4615	4624	4632
4608	4616	4625	

Points with a photogrammetric standard error of latitude greater than 32 m but less than 180 m and an overall standard error of latitude of 0°004 are:

4391	4403	4422	4521
4392	4406	4423	4527
4394	4407	4424	4537
4395	4410	4425	4579
4396	4416	4426	4580
4397	4417	4427	4583
4398	4418	4428	4584
4399	4419	4515	4599
4401	4420	4519	4600
4402	4421	4520	4622

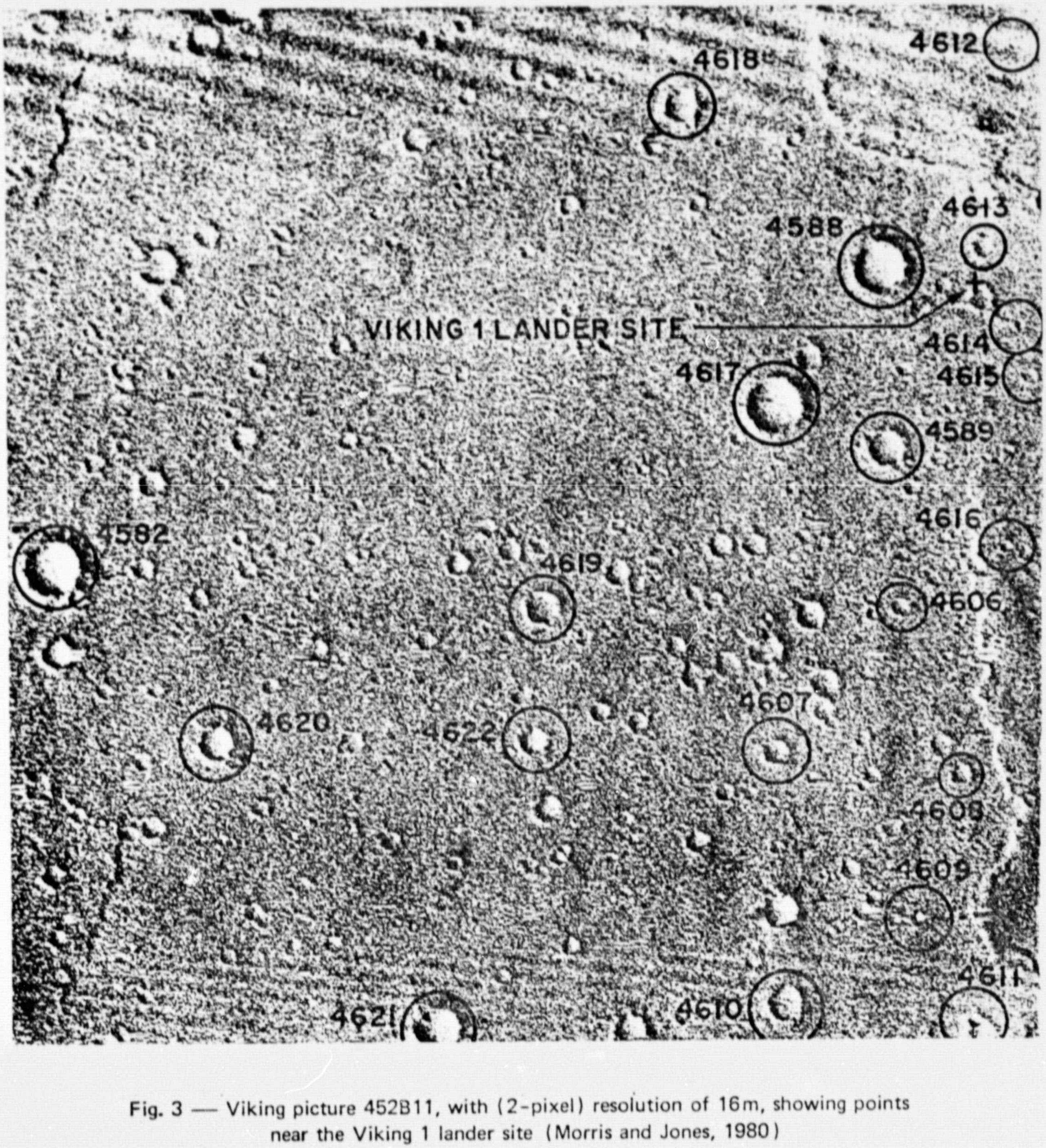

Fig. 3 — Viking picture 452B11, with (2-pixel) resolution of 16m, showing points near the Viking 1 lander site (Morris and Jones, 1980)

Points with a photogrammetric standard error of latitude greater than 180 m but less than about 250 m and an overall standard error in latitude of 0°005 are:

3032	4403
4380	4430
4381	4528
4382	4529
4383	4549
4384	

The remaining points in Table 2, as well as most of the several hundred other points in the strip from Airy-0 to Viking 1 lander for which positions were determined in the GIANT program (but not listed here), had overall standard errors in both latitude and longitude of up to 0°05.

Vertical (elevation) measurements of control points in the vicinity of the Viking 1 lander site have been made. As pointed out by Arthur (1962, 1977), the narrow-angle camera and Viking stereographic sequencing were not optimum for this purpose; pictures taken with wide-angle cameras are preferable for photogrammetric vertical measurements. To make reliable radii computations at control points, the points must be located on Viking stereo pairs and on mosaics included in the planimetric control.

Many points on the high-resolution pictures (452B10-12) at the Viking 1 lander site appeared on only a single pair of pictures with no angular separation; thus reliable measurements of the planetary radii were not possible at these points. A few larger points on these pictures could be measured on the stereo pair 27A33 and 27A63 and also on 20A50 or 20A71 or both. These points measured on four to six pictures did give photogrammetric radii measurements with standard errors less than 100 m. Since the radio experiment's measurement of the planetary radius at the lander site had a standard error of 60 m, the total standard error at these points must be about 120 m. The radii at these points, relative to point 4700 (the Viking 1 lander) with a radius taken as 3389.32 km, are:

Point	Radius (km)
4585	3389.39
4586	3389.44
4588	3389.37
4589	3389.36
4610	3389.42
4617	3389.40
4623	3389.36
4624	3389.31

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